LIST OF FIGURES

Figures

1. Compositional layering of amphibolite and granite gneiss exhibiting open folding.

2. Enclaves of amphibolite in grey porphyritic granite. The alignment of the phenocrysts define the flow lines.

3. Tongue-like intrusion of grey porphyritic granite in pink granite gneiss. Flow lines in porphyritic granite are defined by feldspar phenocrysts.

4. An elongated inclusion of biotite schist in grey porphyritic granite. The flow lines defined by feldspar phenocrysts in porphyritic granite and the lineation in biotite schist are parallel.

5. Spindle-shaped amphibolite in porphyritic granite showing discordant relationship with the latter.

6. Contact of porphyritic granite with granite gneiss. At the discordant contacts the potash feldspar phenocrysts show alignment parallel to the contact.

7. Quartzo-feldspathic vein in grey porphyritic granite.

8. A feldspar phenocryst of grey porphyritic granite with sharp edges and corners.

9. A feldspar phenocryst of grey porphyritic granite with sharp edges and corners, showing twinning.

10. A feldspar phenocryst of grey porphyritic granite showing twinning.
Figures

11 Distinct criss-cross twinning shown by two feldspar phenocrysts.

12 An inclusion of biotite schist in grey porphyritic granite. The flow lines in porphyritic granite is almost perpendicular to the lineation in biotite schist.

13 Contact of grey porphyritic granite with pink granite gneiss. At the contact, the feldspar phenocrysts are augen shaped and biotite segregation is seen.

14 Deformation structures shown by pegmatite veins.

15 A vertical quartzo-feldspathic vein across the foliation with branches of concordant veins which are ptygmatically folded in granite gneiss.

16 Lenses of quartzo-feldspathic material in amphibolite.

17 Lit-par-lit injection of quartzo-feldspathic vein in biotite schist.

18 Quartzo-feldspathic material mimicking the tight asymmetrical folding in granite gneiss.

19 Migmatites formed at the contact of grey porphyritic granite and amphibolite.

20 Tight isoclinal folding ($F_1$) and open folding ($F_2$) shown by interfoliation of granite gneiss and amphibolite $S_1$ is parallel to $S_o$ and both are in turn parallel to the limbs of $F_1$ and $F_2$ fold. Following chapter 4
Figures

21 Quartz vein folded and dislocated along axial plane direction in amphibolite.

22 Open symmetrical folding in granite gneiss.

23 Isoclinal asymmetrical folding shown by interfoliation of quartzo-feldspathic material and biotite schist.

24 Asymmetrical tight isoclinal folding shown by interfoliation of quartzo-feldspathic material and amphibolite.

25 Asymmetrical folding shown by interfoliation of quartzo-feldspathic material and biotite schist.

26 Open asymmetrical folding in granite gneiss.

27 Isoclinal folding shown by interfoliation of quartzo-feldspathic material and biotite schist, characterised by thickening of hinges and thinning of limbs.

28 Open folding characterised by thickening of hinges and thinning of limbs shown by compositional layering of biotite schist and granite gneiss.

29 F_1 isoclinal, F_2 open folding shown by interfoliation of amphibolite and granite gneiss. Refolding of the limbs of F_1 and F_2 folding produces open folding (F_3) of smaller dimensions. The plunge of F_1 is 18° -> 320°.

30 Tight asymmetrical folding in granite gneiss.
Figures

31 Limbs of $F_1$ open fold subjected to refolding ($F_2$) in biotite schist.

32 Refolding of $F_1$ isoclinal folding in granite gneiss.

33 Tension joints in quartzo-feldspathic vein.

34 Equal area projection of 100 poles to foliation planes $S_1$ in granite gneiss. The poles show a concentrated maximum where the foliation dips 40° towards south-east.

35 Equal area projection of 101 poles to foliation planes $S_1$ in granite gneiss. The poles of foliation spread and fall in a well defined girdle. $\beta$ plunges 68° towards north.

36 Equal area projection of 104 poles to foliation planes $S_1$ in granite gneiss. The poles of the foliation show concentration in a maximum, where the foliations dip 16° towards east.

37 Equal area projection of 100 poles to foliation planes $S_1$ in granite gneiss. The poles show a concentrated maximum where the foliation dips 32° towards north-west.

38 Equal area projection of 240 poles of joints in granite gneiss. Here the joints in relation to NE-SW trending foliation are very well developed longitudinal joints.

39 Equal area projection of 157 poles of joints in granite gneiss. The joints in relation to NE-SW...
trending foliation are very well developed horizontal joints, less developed cross joints and least developed longitudinal joint.

40 Equal area projection of 166 poles to joint planes in granite gneiss. The joints in relation to E-W trending foliation planes are: horizontal and longitudinal joints well developed and cross joints less developed.

41 Equal area projection of 172 poles to joint planes in Ganeshpara. The joints in relation to the NE-SW trending foliation planes are well developed diagonal joints, less developed longitudinal joints and least developed cross joints.

42 Frequency diagrams of the strike directions of joint planes at (a) Gorchug
   (b) Saukuchi
   (c) Ganeshpara
   (a) Katabari

43 Rose diagrams displaying the orientations of joint planes at (a) Gorchug
   (b) Saukuchi
   (c) Ganeshpara
   (d) Katabari

44 Flow planes in polar and cyclographic representation and flow lineations on the corresponding great circle. No variations in the directions of flow plane and flow lineations. Three different types of joints are observed: the parallel, cross and longitudinal
Figure

joints. The polar projection of the parallel joint is situated close to the polar projection of the flow planes; that of the cross joint lies very close to the flow lineation.

Flow planes in polar and cyclographic representation and the flow lineation on the corresponding great circle. Strong variation in the orientation of flow structure is observed.

Flow planes in polar and cyclographic representation. Variation in the orientation of the flow plane about the same flow lineation. Longitudinal joint perpendicular to the flow planes and parallel to the flow lineations.

Parallel and cross joints in relation to the planar and linear structures. The polar projection of the parallel joint is situated close to that of the polar projection of flow plane, that of the cross joint lies very close to that of the flow lineation.

Longitudinal joint plane in relation to the flow planes and flow lineation.

NE-SW dipping plane (FP) with three systems of joints; these are parallel (JP) cross (JT) and longitudinal joints, which determine the outcrop form.

Grey porphyritic granite cut by two networks of cross veins one was formed early ($V_1$) and was
Figures

deformed before being cut by straight-sided vein ($V_2$). The veins are filled by quartzo-feldspathic material.

51 Cross quartzo-feldspathic vein (Vt) with included fragments of granite grains (gg).

52 Narrow longitudinal quartzo-feldspathic vein (Vl) in grey porphyritic granite.

53 QAP diagram showing the modal values of quartz, plagioclase and alkali feldspars of granite gneiss (squares), grey porphyritic granite (dots) and fine-grained granite (triangles). The fields (after Streckeisen, 1976) are: 2- Alkali feldspar granite, 3- granite, 4- granodiorite, 7*-quartz-syenite.

54 QPM diagram representing the modal values of quartz, total feldspar, and mica in granite gneiss (squares) and biotite schist (dots). The fields in the diagram show the composition of metamorphic rocks (after Winkler, 1976, p. 329).

55 Inclusions of plagioclase in microcline with albite rim (Ab) in granite gneiss.

56 Myrmekite in contact with plagioclase, microcline and quartz in granite gneiss. The grain boundaries of quartz and plagioclase are serrated.

57 Plagioclase exhibiting albite twinning in granite gneiss, the twin lamellae are very thin.
Figures

58  Displacement of twin lamellae due to minor faulting in granite gneiss.

59  A strained plagioclase with undulose extinction in granite gneiss. The twin lamellae are at right angles to the elongation direction.

60  Inclusions of quartz-I grains in a strained microcline grain in granite gneiss.

61  A strained microcline grain with perthitic lines (Pe-l) and perthitic veinlets (Pe-V) in granite gneiss. Quartz-I grains occur as inclusions in microcline.

62  Cross-cut relationship shown by two generations of biotite in granite gneiss. Bending of a biotite grain is noticed.

63  Cross-cut relationship by two generations of biotite in granite gneiss.

64  Inclusion of zircon in biotite in granite gneiss.

65  Inclusion of zircon in biotite in granite gneiss.

66  Replacement relationship of biotite and microcline in granite gneiss. The grain margin in biotite is corroded.

67  Overgrowth of zircon in granite gneiss.

68  Outgrowth of zircon in granite gneiss.
Figure

69 Quartz-III occurring as worm-like rods within plagioclase giving a symplektitic texture in granite gneiss.

70 A grain where perthitic veinlets transverse strings of perthite which occur along cleavage lines in granite gneiss.

71 Microcline, where perthitic veinlets (Pe-v) transverse direction of the perthitic lines in granite gneiss.

72 Strings of perthite along cleavage directions in microcline. The perthite formation in certain portions is restricted to the cleavage plane, whereas in others it diffuses in granite gneiss.

73 Microcline affected by a system of cracks (resulting in microcline blocks) infiltrated by perthite in granite gneiss.

74 Gneissic texture is granite gneiss.

75 Bending of biotite grain in granite gneiss.

76 Wrinkling and fracturing of biotite in granite gneiss.

77 Interleaving of biotite and hornblende in amphibolite.

78 Post-tectonic plagioclase porphyroblast showing combination of twin lamellae in amphibolite.
Sj and defined by hornblende in hornblende amphibolite. Inclusions of sphene are observed.

Sj, S2 and defined by hornblende in hornblende amphibolite.

Sj defined by biotite-I, S2 defined by biotite-II, and S3 defined by hornblende-III in biotite amphibolite.

Microfolding shown by hornblende prisms in diopside amphibolite.

Sj defined by biotite-I and elongated grains of quartz and plagioclase. S2 defined by biotite-II in biotite schist.

Sj, S2 and S3 directions defined by biotite-I, biotite-II and biotite-III in biotite schist.

Plagioclase showing thin twin lamella at right angles to the elongation direction. Biotite aligned parallel to S1 and S2 foliation directions in biotite schist.

Association of epidote, diopside and garnet in calc-silicate rock. The intragranular spaces between epidote and diopside are occupied by garnet. Inclusions of quartz-I is observed in epidote and garnet.

Association of garnet and diopside surrounded by xenoblastic quartz-II in calc-silicate rock. Inclusions of quartz-I inside garnet is also noticed.
Figures

88 Niggli (al-alk)-c plot of the granite gneiss, amphibolite and biotite schist.

89 Plot of niggli (a-alk) Vs c values of granite gneiss, biotite schist and amphibolites (after Leake, 1964).

90 Niggli 100 mg-c-(al-alk) plot (after Leake, 1964) of amphibolites, granite gneiss and biotite schist.

91 Plots of the amphibolites, granite gneiss and biotite schist of the area on Orville's diagram (1969) niggli mg Vs c, modified from Leake (1964).

92 ACF and A' KF plots of granite gneiss, grey porphyritic granite, fine-grained granite and biotite schist. The triangular diagrams are after Winkler (1976, p.47) and Harris and Goodwin (1976, p. 1204). AA' = andalusite; c = calcite (Wollastonite), F = Talc, Anthophyllite, Cummingtonite, K = K-feldspar, m = muscovite, c = cordierite, a = anorthite, d = diopside, h = hornblende, g = garnet, b = biotite.

93 CaO-Na₂O-K₂O diagram of the granite gneiss. The plotting of gneisses from the Kanakapura area, Karnataka, South India are given for comparison (open circle).

94 K₂O Vs Na₂O diagram of granite gneiss, grey porphyritic granite and fine-grained granite. Plots of Manihari (open circles) and Banresar (cross) granites and 1,2,3,4,5,6 and 7 represent mean composition of Manihari and Banresar, Mayur Hanj
granite (MBG), Arkasani granophyre (ARKG), Chakradharpur pegmatitic granite (CKPG-II), Wolf river granite (WRG), Sicunusa granite (Scun) and Chhotanagpur granite (intrusive variety, CNGP) are shown for comparison.

Plots of granite gneiss, fine-grained granite and grey porphyritic granite in the $K_2O$-$CaO$ discrimination diagrams for the granitic rocks (after Harpum, 1963).

Plotting of $K_2O$ Vs $Al_2O_3$ of the granite gneiss and biotite schist of the area.

Q-Or-Ab+An normative triangular diagram (after Streckeinsen, 1976) of granite gneiss, grey porphyritic granite and fine-grained granite.

The normative orthoclase (Or)-albite (Ab)-anorthite (An) plots of the granite gneiss, grey porphyritic granite and fine-grained granite. The compositional fields in the Or-Ab-An diagram is after Iden (1981, p. 156).

Plots of $Al_2O_3$-$CaO$-$MgO$+$FeO$ of the granite gneiss and biotite schist in the triangular diagram (after Rao et al., 1974, p. 274).

Normative An-Ab-Or plots (after O'Connor, 1965) of the grey porphyritic granite and fine-grained granite.

Q-Ab-Or (normative) diagram for grey porphyritic granite and fine-grained granite. PE-line represents the
projection of cotectic line of $Q$-$Ab$-$Or$-$An$-$H_2O$ system at $pH_2O = 5$ Kb. The plots of Manihari (open circles) and Banresar (cross) granites are shown for comparison.

$SiO_2\%$ Vs $Al_2O_3/(K_2O+Na_2O+CaO \text{ mol. basis})$ plots of grey porphyritic granite and fine-grained granite. Plots of Manihari (dot with square) and Banresar (cross) granite are shown for comparison.

Plots of grey porphyritic granite and fine-grained granite in the $Or$-$Ab$-$An$ system. The line $M-M'$ represents experimentally established minimum melt compositions (recalculated to cation percentages). The arrow denotes increasing $Ab/An$ ratios at $pH_2O=2$Kb (Tuttle and Bowen, 1958; Luth, et al. 1964; Von Platten, 1965; and Von Platen and Holler, 1966).

Variation diagrams showing the weight percentages of oxides, $(K_2O, MgO, FeO, Al_2O_3, SiO_2, CaO)$ of the grey porphyritic granite and fine-grained granite plotted against Larsen Index (after Larsen, 1938).

$Q-P$ 'nomenclature' diagram (Debon and Le Fort, 1982, Debon et al., 1988) for the classification of the grey porphyritic granite and fine-grained granite. $GR=$ granite, $AD=$adamellite, $GD=$granodiorite $QTZ\ SYE=$ quartz syenite and $SYE=$ Syenite. Trends of $THOL$ (tholeiites) and $CALK$ (Calc-alkaline) are also shown.

AFM diagram for the quartzo-feldspathic rocks and basic rocks of the area, demonstrating the broadly calc-alkaline trend, of the granite gneiss, grey
porphyritic granite and fine-grained granite and a tholeiitic trend for the amphibolites.

A-B 'Characteristic minerals' diagram (Debon, et al., 1988) with the CAFEM (Cafemic), ALUM (aluminous) and ALCAF (alumino-cafemic) trends of the grey porphyritic granite and fine-grained granite. Sector I corresponds muscovite and biotite, with muscovite >biotite; Sector II corresponds biotite and muscovite, where biotite >muscovite; Sector III corresponds biotite; and sector IV corresponds amphibole + biotite.

Na$_2$O/Al$_2$O$_3$ Vs K$_2$O/Al$_2$O$_3$ diagram of grey porphyritic granite and fine-grained granite.

SiO$_2$ Vs FeO/MgO variation diagram of the granite gneiss, grey porphyritic granite, fine-grained granite and amphibolite.

(FeO+Fe$_2$O$_3$+TiO$_2$)- MgO-Al$_2$O$_3$ plot of the granite gneiss, grey porphyritic granite, fine-grained granite and amphibolite.

Plots of TiO$_2$ (wt %) as against Iron enrichment ratio (FeO+Fe$_2$O$_3$)/(FeO+Fe$_2$O$_3$+MgO) wt % of the amphibolites.

ACF plots of the amphibolites, showing composition field of basic igneous rocks indicated by discontinuous line (after Orville, 1969).

Plot of total alkali weight percentage (Na$_2$O+K$_2$O) as against silica (SiO$_2$). The amphibolites of the area falls in the tholeiitic field.
Differentiation diagram (felsic index vs mafic index) after Simpson (1954). The amphibolites of the area plot in the middle stage basalt field.

Plots of $\text{SiO}_2$ (wt %) as against $\frac{\text{FeO}^+}{\text{MgO}}$ of the amphibolites of the area in the differentiation diagram (after Miyashiro 1974) ($\text{FeO}^+ = \text{total iron}$).

Plots of $\text{FeO}$ (wt %) versus $\frac{\text{FeO}^+}{\text{MgO}}$ (wt %) of the amphibolites in the differentiation diagram after Miyashiro (1975). $\text{FeO}^+ = \text{total iron}$.

Plots of niggli values $k$, alk, $t1$, c against mg for analysed amphibolites.

Plots of niggli values, al, fm, c, alk against si for analysed amphibolites.

Plots of $\text{Mg}- (\text{Fe}'' + \text{Fe}''' )- (\text{Na}+\text{K})$ and Ca-K-Na for the analysed amphibolites. Average composition of 137 tholeiitic basalts and dolerites (N) Nockolds, 1954, and 19 basites (P) Parks, 1966 are given for comparison.

Variations of the individual oxide contents of the amphibolites plotted against Solidification Index. Differentiation trends of the Palisades sill (after Kuno, 1965) are given for comparison.

Normative compositional diagrams (after Naqvi, 1975) showing the compositional range of the amphibolites.
Figures

122 ACF plots of granite gneiss, biotite schist and amphibolite depicting chemical variation in terms of Al$_2$O$_3$, CaO and (Mg, Fe)O (after Turner, 1968, Fig. 5-2).

123 A-B diagram of grey porphyritic granite and fine-grained granite (after Debon and Le Fort, 1982; Debon et al., 1986).

124 QBF projection of grey porphyritic granite (after Debon and Le Fort, 1982 and Debon et al. 1986).

125a Negative correlation of the modal values of microcline (K) and plagioclase (PL) in granite gneiss

125b Negative correlation of the modal values of quartz (Q) and plagioclase (PL) in granite gneiss.

126 Q-Ab-Or diagram for granite gneiss (big triangles). The field of granitic rock is enclosed by continuous line, and includes 86% of all the granites. The stippled area includes 14% and constitutes the maxima. Solid circles indicate points of "minimum melt" composition and thinner lines the cotectic lines at various Ab/An ratios.

127 (Al$_2$O$_3$) - (Na$_2$O + K$_2$O + CaO) - (FeO + MgO + MnO) diagram for the biotite schist (dot in circle) and the granite gneiss (big triangles). The plots of the granitic rocks (small triangles) and pelitic rocks (dots) of Masl area, Kumaun Himalaya are shown for comparison.